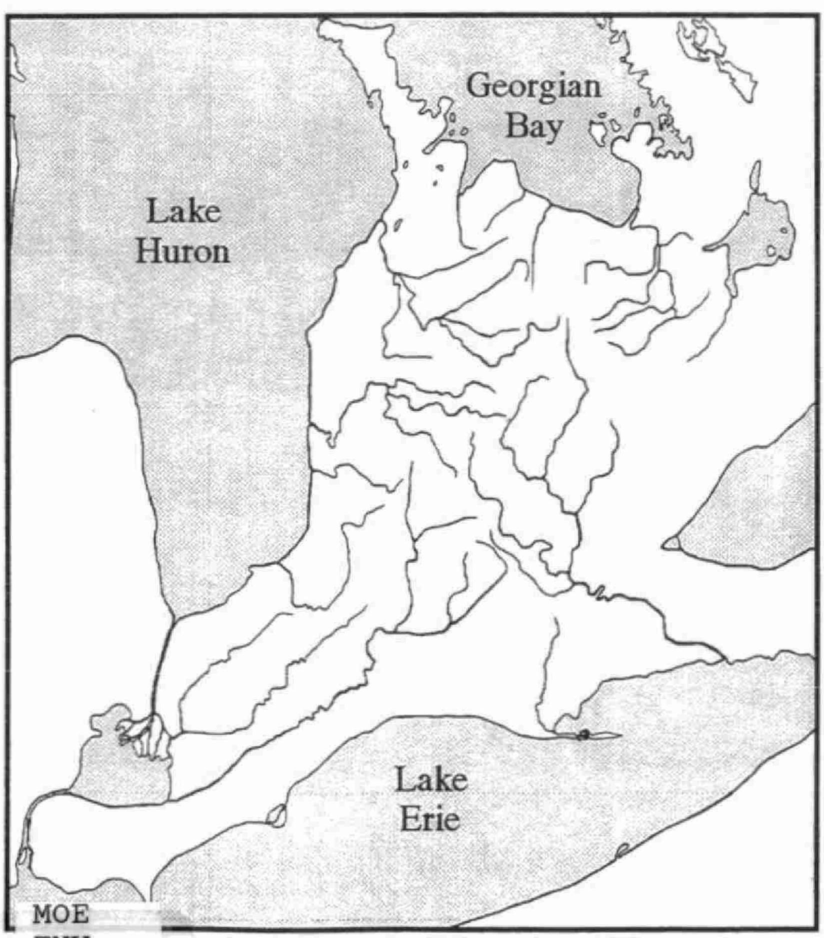
BioMAP Report SWR- 4

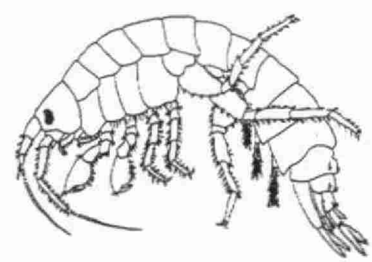
Ministry of Environment and Energy
Southwestern Region
Water Resources Assessment Unit
985 Adelaide St. South
London, Ontario N6E-1V3

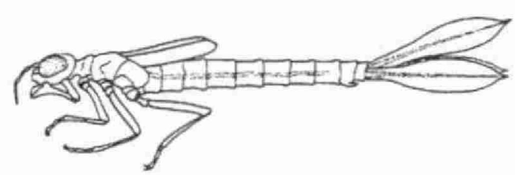
A BIOLOGICAL MEASURE OF WATER QUALITY FOR CREEKS, STREAMS AND RIVERS

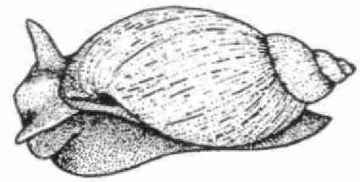
by

Dr. Ronald W. Griffiths









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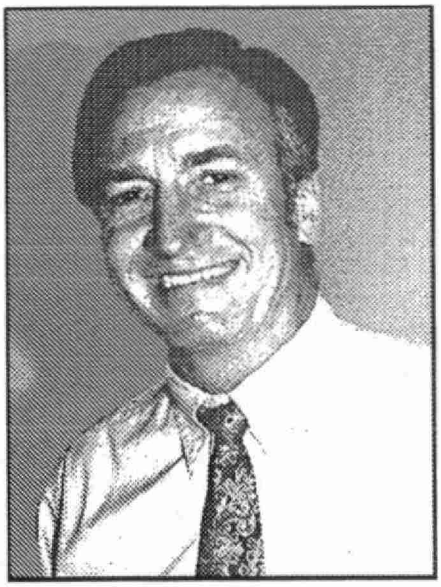
This report is dedicated to Denis Veal



in recognition of his 30 years of work
in environmental assessment and conservation with the
Ontario Ministry of the Environment and Energy.

A Biological Measure of Water Quality for Creeks, Streams and Rivers

A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise. (Leopold 1949)

1. Introduction:

Water quality is a valued public resource; aquatic systems with unimpaired water quality satisfy a wide variety of needs (e.g. fishing, food, recreation, aesthetic, irrigation, waste assimilation, education), whereas polluted systems with impaired water quality satisfy few needs, if any, and frequently pose health concerns for local residents, livestock and wildlife. Because water pollution is defined by its affect on living organisms, assessment of water quality is principally conducted using biological measures. Since the early 1900's, researchers in different parts of the world have developed a number of biological methods to measure and classify the water quality of riverine systems (e.g. Kolkwitz and Marsson 1908; Forbes 1913; Richardson 1928). Biological indices, such as the various types of community, diversity, biotic indices and more recently, indices of biotic integrity, have been and continue to be the most widely used measures to evaluate water quality at specific sites (Rosenberg and Resh 1992). While diversity indices have been continuously shown to be poor measures of water quality, the other groups of biological indices have successfully measured specific water quality aspects at least on a regional scale (Washington 1984). The quest for the wholly grail (i.e. a perfect water quality measure) continues, however, because many indices were designed to address a single type of degradation (e.g. organic enrichment, metals, pesticides), typically from point-sources (sewage treatment plants, pulp mills, industrial discharges), or are only applicable within a restricted geographic area or ecoregion (Lenat 1993; Washington 1984).

A standardized system of sampling and evaluating water quality is a vital component of any water resource management and land-use planning program. It provides directly comparable information about the relative, if not absolute, water quality conditions at sites along a river system, between river systems, and over time. A standard method of evaluating water quality also eliminates the perception that the method may have been selected solely to provide a specific conclusion and thus increases the public's confidence of that conclusion. Furthermore, public groups can participate in assessing water quality conditions because standardized methods of data

collection and water quality assessment allow the production of comparable information (e.g. Penrose and Call 1995; Firehock and West 1995).

The purpose of this report is to outline a standardized biological measure (biotic index) that provides a direct measure of water quality for riverine systems throughout southwestern Ontario, the predominant inland aquatic feature in this geographic area. Because agricultural activities and urbanization are the main environmental stresses on the landscape, this measure was developed to be responsive to the effects of non-point sources. Deforestation, agricultural activities and urbanization are well documented ecological stresses that degrade water quality (i.e. the ability of a stream to support aquatic life and human uses) by increasing sediment, nutrient and contaminant loadings, altering energy flows (e.g. leaf litter) to the stream, changing the water detention/retention ability of the drainage basin, and modifying habitat characteristics (physical structure) and the temperature regime of the stream (e.g. Limburg and Schmidt 1990; Steedman 1988; Frank and Logan 1988; Bird 1987; Hetherington 1987; MacKenzie 1987; Barton et al. 1985; Peterjohn and Correll 1984; Hill 1981; Klein 1979; Slaney et al. 1977; Hynes 1975; van Vliet et al. 1976; Hammer 1972; Brown and Krygher 1970). Since benthic macroinvertebrates are known to respond to changes in these variables (Hynes 1970; Lemly 1982; Vanotte et al. 1980; Resh and Rosenburg 1984), they are used as the basis for the biological measure described herein. The advantages of using benthic macroinvertebrates as indicators of water quality are well known (Griffiths 1993), especially that noted by Forbes (1913): biological observations are more dependable than chemical determinations since they show cumulative effects of present and past conditions, while chemical tests apply only to the moment of sampling. Although benthic macroinvertebrates have little social relevance, they are an important food source for fish and waterfowl, organisms that the public relate with unimpaired environmental conditions.

2. BioMAP Water Quality Index:

All indices are abstractions of the real world; their primary purpose is to summarize data from a system into a simple form that conveys knowledge about the quality/dynamics of that system to experts and non-experts (e.g. Toronto 300 index or Dow Jones). These indices or models should capture the essence of the system under study, while being as simple as possible. An index thus can be expected to effectively convey a single concept about a system, but cannot be expected to convey a multitude of independently varying concepts with any effectiveness; one index cannot do everything.

Large-scale studies (surveys, experiments) generate sufficient data (numerous independent sampling points) to explore or test specific ideas and hypotheses using multivariate statistics, modelling, or other mathematical techniques of analysis. Small-scale studies, meanwhile, typically generate data from only a handful of sites and thus lack the degrees of freedom necessary to explore or test specific ideas. Most types of statistical or other mathematical techniques of analyses thus cannot be used to effectively analyze these data. One means to analyze data from small-scale studies is to construct indices based on information and knowledge generated from the large scale studies in order to assess to a specific concept such as water quality.

Biotic indices (e.g. Chutter index, Trent Index, Beak's Index, Hilsenhoff's index) have long been used to translate benthic macroinvertebrate data into a measure of water quality. They typically incorporate information about the ecological requirements of individual macroinvertebrate taxa with a measure of their abundance. The same idea is followed here:

A quantitative measure of water quality (WQ) at a site can be estimated from:

$$WQ = \left[\sum^{n} \left(e^{SV_i} * \ln(x_i + 1)\right)\right] \div \left[\sum^{n} \ln(x_i + 1)\right],$$

where SV_i is the sensitivity value of the i^{th} taxon,
x_i is the density of the i^{th} taxon,
n is the number of taxa in the sample,
ln is the natural logarithm.

Water quality thus is expressed as the abundance-weighted mean sensitivity value of the benthic macroinvertebrates occurring at a site. The index uses all benthic macroinvertebrates (see definition in Griffiths 1993) collected in a sample, not just a few indicator taxa. Although a biomass-weighted mean sensitivity value may provide a better measure of water quality, the difficulty of obtaining the fresh (non-preserved) weight of macroinvertebrates identified to the generic or specific level prohibits its use. The logarithm of density thus is used to reflect biomass (rare, large things given proportional more weight than abundant, small things). Finally the sensitivity values (SV) contribute proportional, not arithmetically, to the measure of water quality; rare taxa that are most intolerant of environmental disturbances or stresses (i.e. require the most "pristine" conditions) contribute 54.6 times more to the measure of water quality than taxa that can tolerant wide ranges and fluctuations of environmental conditions (see next section for details).

3. Macroinvertebrate Sensitivity Values:

Tolerance values have been assigned to benthic macroinvertebrates typically based on their perceived, observed or measured tolerance to organic pollution (e.g. sewage, pulp and paper wastes) and reduced dissolved oxygen concentrations (e.g. Richardson 1928; Chandler 1970; Chutter 1972; Hilsenhoff 1977, 1987; Rabeni et al. 1985; Lenat 1993). Data, however, is currently available to assign values based on their tolerance to dissolved metals, acidity, or nutrients (Hart and Fuller 1974; Winner et al. 1980; Otto and Svensson 1983; Mance 1987).

I have assigned sensitivity values to benthic macroinvertebrates (Appendix A) based on their location within the riverine system where they are most commonly abundant. Starting with Illies (1961) classification of riverine systems into a rhithron and potamon section, I have further split each section into 2 parts, thus identifying four riverine units: creeks and streams within the rhithron, and rivers and large rivers within the potamon. These units are functional defined as:

1. creeks:
   - most upstream reach of a riverine system
   - bankfull width <4m
   - principally first and second order systems
   - closed canopy
   - cold or cool water

2. streams:
   - bankfull widths of 4 to 16m
   - principally third and fourth order systems
   - partially open canopy
   - cold, cool or warm water

3. rivers:
   - bankful widths of 16 to 64 m
   - principally fifth and sixth order systems
   - open canopy
   - cool and warm water

4. large rivers - most downstream reach of a riverine system
- bankful widths > 64m
- principally seventh and greater order systems
- open canopy
- warm water

Lakes represent the fifth and final (most downstream) aquatic system category and include all lentic systems (e.g. lakes, pond) in which there is no discernible unidirectional flow.

Macroinvertebrate species typically occur within a specific longitudinal section of a riverine system (Carpenter 1928; Ide 1935, 1940; van der Schalie 1938; Illies 1958; Maitland 1966; Ward 1986; Harrison and Hynes 1988); conspecific species may sequentially replace one other along the length of stream (Macan 1957; Hallam 1959). The River Continuum Concept provides one basis to explain this general distributional pattern (Vanotte et al. 1980). It is also known that the mean value of environmental variables (e.g. temperature, dissolved oxygen, suspended solids) change along the length of riverine systems and that the variation in these environmental variables increases with distance downstream from the headwaters. The assignment of sensitivity values is based on the premise that the tolerance of lotic (running water) benthic species to environmental variables (e.g. suspended solids, oxygen, nutrients, temperature) increases with distance from headwater sources towards the lentic (still water) receiver, matching the increase in the variation of environmental variables along this longitudinal gradient. In other words, species restricted to headwater creeks are more sensitive to changes in minimum/maximum values or daily/seasonal variation of environmental variables than those inhabiting streams or rivers, and those taxa abundant in ponds and other lentic systems are those most tolerant to variations in environmental variables.

The assigned sensitivity values vary from 4 to 0 with:

4 being assigned to any taxon that is commonly abundant in headwater creeks;
3 being assigned to any taxon that is commonly abundant in streams;
2 being assigned to any taxon that is commonly abundant in rivers and rocky nearshore areas of lakes;
1 being assigned to any taxon that is commonly abundant in large rivers and riverine marshes;
0 being assigned to any taxon that is commonly abundant in lentic systems (e.g. lakes, ponds, mud puddles, temporary pools).

The BioMAP WQI, therefore, can range from 0 (no organisms) to 54.6, but typical values range from 5 to 25. The assignment of sensitivity values to specific benthic macroinvertebrates was made based on abundance and site characterization data collected over the past 15 years from over 200 sampling sites throughout southwestern Ontario and supplemented with additional information from the literature. Almost 600 taxa have been assigned a sensitivity value to date (Appendix A).

Not all benthic macroinvertebrates have been assigned sensitivity values. Conspecific taxa of some genera: e.g. *Orthocladius*, *Cricotopus*, *Tipula*, *Pisidium*, *Cheumatopsyche*, are known to inhabit different aquatic habitats and since it is difficult to taxonomically identify the species in these species-rich genera, they cannot be assigned a unique sensitivity value. Furthermore, some taxa have so rarely been collected that it is not yet possible to determine in which river unit they are commonly abundant. These taxa thus are not used to estimate the water quality conditions at a site.

Not all taxa must be identified to species to be assigned a sensitivity value. In many cases a sensitivity value can be assigned to a genus because the few species in that genus that occur in southwestern Ontario inhabit the same aquatic habitat, as far as is currently known. Benthic macroinvertebrates, therefore, must be identified to the taxonomic level provided in Appendix A in order to be considered in the water quality assessment. Taxonomic keys to assist with the identification of benthic macroinvertebrates are provided in Appendix B. Young instars/nymphs that cannot be identified to the level indicated in Appendix A are not used to estimate the water quality conditions at a site. As new taxonomic and biological information comes available, the values in Appendix A can be updated to reflect current knowledge. The version number at the bottom of the page should be reported when using the BioMAP water quality index.

4. Water Quality Classification:

Typically, the water quality of riverine systems is classified as excellent, good, fair, poor, etc. (e.g. Hilsenhoff 1977, 1987; Lenat 1993). Unfortunately, these terms impose a value system on the water resource. Excellent water quality becomes synonymous with clear, cool, fast-flowing trout streams; as a consequence, highly productive bass rivers become associated with a lower level of water quality, although they are unimpaired! It is essential to disassociate this type of value system from a water quality classification scheme.

The Ontario Water Resources Act states that: the quality of water shall be deemed to be <u>impaired</u> if:

the material discharged or caused or permitted to be discharged or any derivative of such material causes or may cause injury to any person, animal, bird or other living thing as a result of the use or consumption of any plant, fish or other living matter or thing in the water or in the soil in contact with the water.

(R.S.O. 1990, c. O.40, s.28)

Ecological definitions for <u>unimpaired</u> and <u>impaired</u> water quality thus can be derived from this legislation: Water quality can be classified as <u>unimpaired</u> at any place where the community of organisms is <u>not</u> primarily determined by an anthropogenic factor; it is <u>impaired</u> when it tends otherwise.

Unimpaired water quality thus will be recognized by the occurrence of macroinvertebrates whose environmental requirements match those expected at that site; i.e. creeks should contain "creek-dwelling" species if the water quality is unimpaired. Because each riverine system is somewhat unique, no single reference community can be used to judge impairment; different mixes of species (communities) can reflect unimpaired water quality conditions. Impaired water quality, meanwhile, will be recognized by the occurrence of species that are "out of place"; for example, the predominance of "stream-dwelling" macroinvertebrates in a headwater creek, or the predominance of "lake-dwelling" macroinvertebrates in a river. The general effect of pollution thus is to shift the longitudinal zonation of benthic macroinvertebrates in the upstream direction.

Empirical results from over 60 riverine sites throughout southwestern Ontario suggest that water quality can be correctly classified as unimpaired or impaired more than 90% of the time using values from the BioMAP water quality index (WQI) as listed in Table 1.

Table 1: Classification of water quality at sites in creeks, streams and rivers based on values from the BioMAP water quality index. ? denotes that the water quality may be unimpaired or impaired.

	Water Quality Classification		
BioMAP WQI	Creeks	Streams	Rivers
> 14	unimpaired	unimpaired	unimpaired
14 - 12	?	unimpaired	unimpaired
12 - 10	impaired	?	unimpaired
10 - 8	impaired	impaired	?
< 8	impaired	impaired	impaired

Thus the water quality at a stream site with a BioMAP WQI value greater than 12 is unimpaired; whereas, the water quality at a stream site with a BioMAP WQI value less than 10 is impaired. If the BioMAP WQI value at a stream site is between 10 and 12, then no conclusion can be drawn based solely on this WQI-- the water quality may be impaired or unimpaired. This "gray" zone in the index has been established to deal with the uncertainty in the classification of water quality among water quality experts (Figure 1). For BioMAP WQI values greater than the maximum threshold value defining the gray zone, more than 90% of water quality experts would agree that the water quality is unimpaired when it is actually unimpaired; similarly, for BioMAP WQI values lower than the minimum threshold value defining the gray zone, more than 90% of water quality experts would agree that the water quality is impaired when it is actually impaired. For BioMAP WQI values within the gray zone (i.e. between the threshold values), experts will be less likely to agree on the water quality classification because they each weigh components of the system in a different manner based on their experience and training to judge water quality. Some of these components will suggest impairment, others will suggest no impairment. A consensus will be difficult.

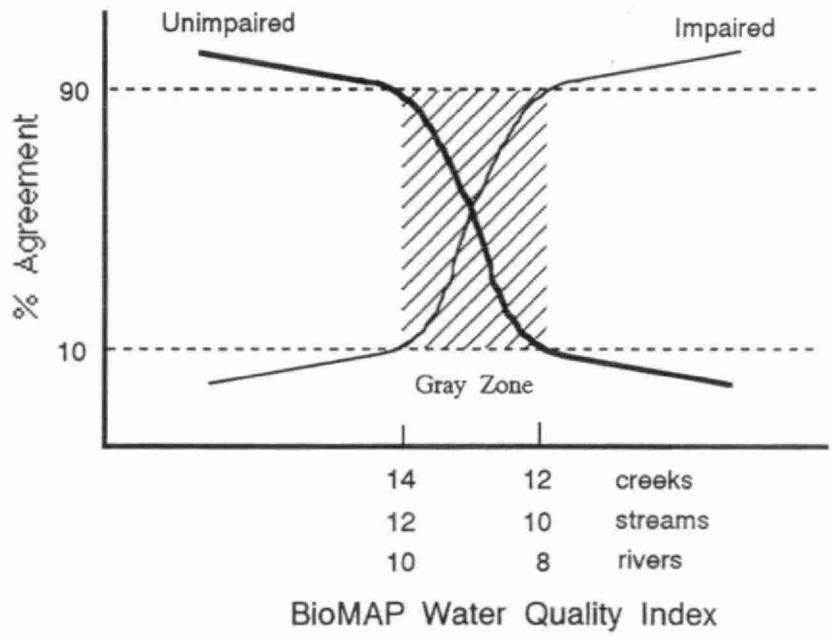


Figure 1: Decision Phase Space: Relationship between % agreement among water quality experts and water quality of an aquatic system as measured by the BioMAP water quality index. Water quality is classified as unimpaired or impaired when 90% or more of the experts are in agreement.

Note that the threshold BioMAP WQI values (i.e. the minimum value that defines unimpaired water quality and the maximum value that defines impaired water quality) decline as the size of the riverine system increases (i.e. from creek to stream to river), reflecting the change in the predominant group of benthic macroinvertebrates in each riverine unit. It is critical to the analysis of water quality, therefore, that the sampling site be classified as a creek, stream, or river using the functional definitions in section 3, prior to calculating the BioMAP WQI value.

It is preferable that all benthic macroinvertebrates collected in a sample be identified and those with a sensitivity value be included in calculation of the BioMAP water quality index. As a rule of thumb, however, the identification of worms may be omitted if they account for <10% of the total number of organisms in the sample and similarly, the identification of chironomids may be omitted if they account for <20% of sample, provided that at least 100 organisms were collected. The omission of these groups appears to have little effect on the BioMAP WQI value and no effect on the classification of water quality. Whenever possible, select a size of sampler that will yield 200-400 benthic macroinvertebrates on average from the enclosed sampling area. This size of sampler then will likely provide a minimum of 100 organisms. Water quality conclusions should not be made from BioMAP WQI values if based on a sample with less than 25 organisms.

5. Test of the BioMAP Model:

To verify that the BioMAP water quality index reflects environmental stress associated with land-use activities in a catchment, the mean WQI was calculated at 19 sampling sites in five catchments from paired benthic macroinvertebrate samples collected with a Surber sampler that enclosed an area of 0.092 m^{-2}. Land-use maps from the Ontario Ministry of Agriculture and Foods were digitized and the area of five land-use categories (wildlands, intensive agriculture, grain & hay, pasture, urban) was calculated upstream of each sampling point using the GIS program Map•Factory from ThinkSpace, Inc. of London, Ontario. The WQI was regressed against the land-use categories using the model:

WQI = constant + wildlands + intensive agriculture + grain & hay + pasture + total.

Total represented the total size of the drainage basin upstream of a sampling site and was included as a covariant in the model. Urban accounted for only a small proportion of the land-use in these catchments; it is included indirectly in the model as total minus the other 4 land-use categories.

The first canonical variant was used to represent the composite variable, "land-use", to analyze the relationship between water quality and land-use (Figure 2). Land-use within the catchment explained 68% of the variation in the WQI. Water quality was found to be better at sites with a higher proportion of wildlands (i.e. forest, wetlands, reforested, agricultural land idle for >10 yr.) and a lower proportion of intensive agriculture (i.e. corn, row crops, market gardens, orchards) upstream of the sampling point. The BioMAP WQI thus responded in the predicted manner to land-use activities (i.e. non-point source pollution).

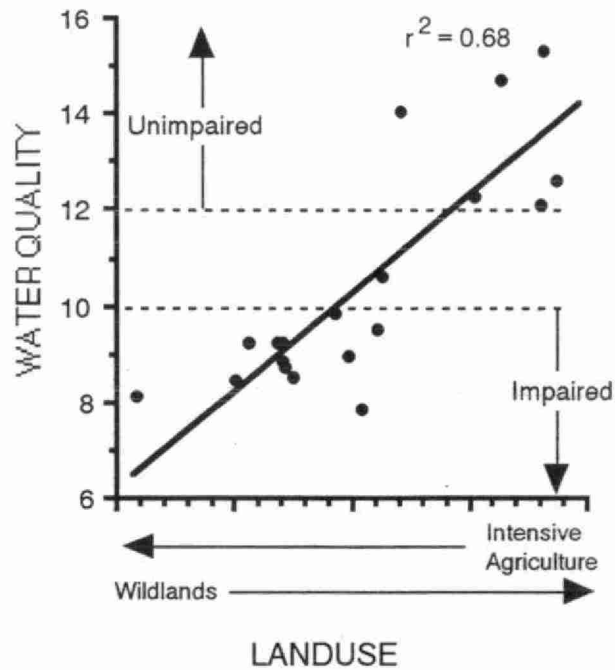


Figure 2: Relationship between water quality and upstream land-use in Grey County drainage basins. Data from the Pretty River, Rocky Saugeen River, Meaux Creek, Carrick Creek and Otter Creek.

6. Discussion:

Current water quality assessment depends on the identification of unimpaired or "reference" sites. The benthic fauna at a new "test" site then is compared to the fauna at these reference sites via some statistical or mathematical technique (e.g. Reynoldson et al. 1995; Barton 1996). If the test site fauna "matches" that at one of the references sites, then the water quality at the test site is classified as unimpaired, otherwise it is classified as impaired. This assessment method implicitly assumes that there exists a discrete (limited) number of identifiable unimpaired communities types

that vary little over time. Unfortunately, all riverine systems are somewhat unique; thus a reference site community may simply not exist for a specific test site. Furthermore, few undisturbed sites remain in southwestern Ontario, particularly in Essex, Kent and Lambton counties where forest cover now accounts for less than 5% of the land base. In addition, the faunal composition of reference sites may show dramatic changes seasonally and annually and thus at the very least must be resampled each time a the test site is sampled, dramatically adding to the cost and complexity of the study. Finally, this method fails to consider the longitudinal zonation of species (Hynes 1970) that has been repeatedly observed over the past century in riverine systems throughout the world.

The water quality assessment system proposed in this report attempts to address these issues by removing the reliance on specific unimpaired reference sites to classify water quality. The BioMAP water quality measure, instead, relies on our distributional knowledge of benthic macroinvertebrates within riverine systems and present ecological understanding of lotic (i.e. running water) systems to classify the water quality at a site. Although the composition of benthic macroinvertebrates changes down the length of a riverine system (i.e. from creeks, to streams, to rivers), unimpaired water quality occurs where the mix of benthic macroinvertebrates matches that expected from our distributional knowledge of those macroinvertebrates (i.e. creek-dwelling macroinvertebrates occurring in a creek; river-dwelling macroinvertebrates occurring in a river). The faunal composition at a test site thus need not match that at one of a finite number of undisturbed sites; it simply must contain a mix of species appropriate for that riverine unit (i.e. creek, stream, river), which is evaluated by comparing the BioMAP WQI value for the test site to those contained in Table 1. Seasonal and annual changes in the faunal composition at a site have little effect on the BioMAP WQI as long as creek-dwelling taxa are replaced by other creek-dwelling taxa, etc.; the index does not depend on the specific taxa at a site to evaluate water quality, but on the information those taxa infer about the site. Fortunately, information on the zonal distribution of a species, on which its sensitivity value is based, is not dependent on the few undisturbed sites in southwestern Ontario, but can be based on both historical and current data from throughout its range.

It must be made clear that the BioMAP WQI only conveys information on the water quality status (unimpaired, impaired) at a site and does not provide a measure of resilience -- ability to absorb disturbances and thus resist change. Sites with low resilience are considered "fragile"; they have little ability to resist change and thus small disturbances may result in large changes in the community composition. Sites with high resilience are considered "robust"; they have the ability to absorb a wide range of disturbances and show little change in community composition as a consequence. Fragile, unimpaired water quality sites are important to identify as soon as possible

because they unable to withstand further stress without rapidly degrading. Robust, unimpaired water quality sites, meanwhile, are still forgiving of abuses. Fragile, impaired water quality sites are good candidates for rehabilitation activities, since a small reduction in stress can lead to large improvements in water quality. Robust, impaired water quality sites, meanwhile, require a great deal of resources and time to achieve even a small improvement in water quality. Developing a system to measure resilience is an area for productive further research.

The BioMAP WQI offers several advantages over other water quality assessment methods:
a) it provides a rapid, low-cost, standardized method, allowing a variety of groups (e.g. public, government, academic, industry) to collect comparable data;
b) it provides sensitivity values based on the local benthic macroinvertebrate fauna, not that of Wisconsin (Hilsenhoff 1987), North Carolina (Lenat 1993), Britain (Armitage et al. 1983), etc., thus improving the accuracy of the measure;
c) it can be used in small studies that sample only a few sites;
d) it reflects effects from non-point and point source pollution;
e) it provides quantitative data from a single habitat -- riffles are preferred because they yield the most taxa and specimens (see Griffiths 1993 for details on sampling);
f) it provides an estimate of inter-sample variation at a site thus allowing for statistical comparisons over time or between sites;
g) it provides a single measure of water quality that can be incorporated easily into a computer spreadsheet for calculation (see Appendix C).

Furthermore, this method provides more than just a measure of water quality at a riverine site. By monitoring the WQI at a site over time, it can provide an early warning indication of water quality degradation or assess the water quality benefits of an upstream abatement or rehabilitation activity. At impaired water quality sites, the type of stress causing the impairment (e.g. organic or nutrient enrichment, metals, pesticides, mineral sediments) can be inferred directly from the faunal composition used to calculate the BioMAP WQI, or from indices (metrics) that use the faunal composition data (e.g. % tubificids to indicate organic enrichment; % chironomids to indicate heavy metal effects). The WQI may also be used to provide a measure of summer maximum water temperature or identify trout habitat since the distribution of benthic macroinvertebrates is known to respond to water temperature (Ide 1935; Hynes 1970). Finally, the BioMAP WQI provides a means to measure not only the health of riverine systems in southwestern Ontario but their catchments also, since land-use changes in a drainage basin affect the quality and flow of a river by altering interactions between the "stream and its valley" (Hynes 1975; see Figure 2 above). The WQI reflects more than just the chemical composition of the water.

Once the macroinvertebrate fauna is known within a local area, a Family-level WQI can be developed from the detailed species abundance data (e.g. Hilsenhoff 1988), so that public groups may determine water quality on a real-time basis. A reference collection of benthic macroinvertebrates sorted to family, can readily be used by non-experts to identify macroinvertebrates from a test site. Once established, this screening method allows water quality determinations with little taxonomic expertise. Marked changes in the Family WQI can always be verified later using the BioMAP WQI, since the biological samples can be maintained in 80% alcohol indefinitely.

7. Acknowledgments:

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Appendix A: Sensitivity values for common riverine macroinvertebrates occurring in southern Ontario. Values range from 4 to 0; higher values indicate that that taxon's greatest abundance occurs higher upstream in the catchment and thus is more sensitive to variation inenvironmental variables. Taxa with a value of 4, thus, are most abundant in creeks, 3 in streams, 2 in rivers (also found along rocky, wave-swept shores of lakes), 1 in large rivers and riverine wetlands, and 0 in lakes, marshes, and ponds (i.e. lentic habitats). ? denotes insufficient data to establish a value. -- denotes value cannot be established.

Macroinvertebrate Taxa	Sensitivity Value
Insects:	
ALDERFLIES:	
Corydalidae:	
Chauliodes	1
Corydalis	2
Nigronia	3
Sialidae:	
Sialis	2
AQUATIC MOTHS:	
Pyralidae:	
Petrophila	2
others	0
BEETLES:	
Dyropidae:	
Helichus	2
Dytiscidae:	
Acilius	0
Agabetes	0
Agabus	2
Bidessonotus	1
Celina	0
Colymbetes	1
Copelatus	3
Coptotomus	1
Cybister	0
Deronectes	2
Desmopachria	0
Dytiscus	1
Graphoderus	0
Hydroporus	2
Hydrovatus	0
Hygrotus	0
Illybius	2
Laccophilus	0
Laccornis	1
Liodessus	2
Matus	2
Neoscutopterous	0
Oreodytes	2
Rhantus	0
Uvarus	2

Macroinvertebrate Taxa	Sensitivity Value
Elmidae:	
Ancyronxy variegata	2
Dubiraphia bivittata	0
Dubiraphia minima	1
Dubiraphia quadrinotata	1
Dubiraphia vittata	2
Macronychus galbratus	2
Microcylloepus pusillus	3
Optioservus fastiditus	2
Optioservus ovalis	2
Optioservus trivittatus	3
Promoresia elegans	3
Promoresia tardella	4
Stenelmis bicarinata	2
Stenelmis crenata	2
Stenelmis musgravei	1
Stenelmis quadramaculata	0
Stenelmis sandersoni	2
Stenelmis vittipennis	2
Gyrinidae:	
Dineutes	2
Gyrinus	1
Haliplidae:	
Haliplus	1
Peltodytes	1
Hydrophilidae:	
Anacaena	?
Berosus	0
Crenitis	2
Cymbiodyta	1
Enochrus	0
Helocombus	?
Helophorus	1
Hydrobius	1
Hydrochara	?
Hydrophilus	3
Laccobius	1
Paracymus	?
Sperchopsis	2
Tropisternus	0
Limnichidae:	
Lutrochus	3

Macroinvertebrate Taxa	Sensitivity Value
Psephenidae:	
Ectopria	3
Psephenus	3
Ptilodactylidae:	
Anchytarsus	3
BUGS:	
Belostomatidae:	
Belostoma	0
Lethocerus	0
Corixidae:	
Callicorixa	2
Corisella	0
Hesperocorixa	1
Palmacorixa	2
Sigara grossolineata	2
Sigara lineata	2
Sigara mathesoni	3
Sigaratrilineata	2
Sigara (others)	0
Trichocorixa	1
Gerridae:	
Aquarius	3
Gerris	1
Limnoporus	1
Metrobates	2
Neogerris	0
Rheumatobates	1
Trepobates	1
Mesoveliidae:	
Mesovelia	1
Nepidae:	
Nepa	1
Ranatra	0
Notonectidae:	
Buenoa	0
Notonecta	0
Pleidae:	
Neoplea	0
Veliidae:	
Microvelia	0
Rhagovelia	2
CADDISFLIES:	
Beraeidae:	
Beraea	4

Macroinvertebrate Taxa	Sensitivity Value
Brachycentridae:	
Brachycentrus	3
Micrasema	4
Calamoceratidae:	
Heteroplectron	3
Dipseudopsiidae:	
Phylocentropus	2
Glossosomatidae:	
Agapetus	4
Glossosoma	4
Protoptila	2
Goeridae:	
Goera	3
Helicopsychidae:	
Helicopsyche	2
Hydropsychidae:	
Aphropsyche	4
Cheumatopsyche	---
Diplectrona	3
Hydropsyche alhedra	3
Hydropsyche alvata	1
Hydropsyche betteni	2
Hydropsyche bronta	3
Hydropsyche cuanis	2
Hydropsyche dicantha	2
Hydropsyche hageni	2
Hydropsyche morosa	2
Hydropsyche orris	2
Hydropsyche placoda	2
Hydropsyche scalaris	2
Hydropsyche slossonae	3
Hydropsyche sparna	3
Hydropsyche ventura	4
Hydropsyche walkeri	3
Macrostemum	2
Parapsyche	4
Potamyia	1
Hydroptilidae:	
Agraylea	1
Hydroptila	2
Ithytrichia	4
Leucotrichia	3
Mayatrichia	2
Neotrichia	2
Ochrotrichia	1
Oxyethira	1
Stactobiella	4

Macroinvertebrate Taxa	Sensitivity Value
Lepidostomatidae:	
Lepidostoma	4
Theliopsyche	4
Leptoceridae:	
Ceraclea	1
Leptocerus	0
Mystacides	1
Nectopsyche	1
Oecetis	2
Setodes	2
Triaenodes	1
Limnephilidae:	
Anabolia	1
Apatania	4
Asynarchus	1
Chyranda	4
Frenesia	4
Glyphopsyche	1
Hesperophylax	3
Hydatophylax	4
Ironoquia	2
Lenarchus	1
Limnephilus	1
Nemotaulius	1
Onocosmoecus	4
Platycentropus	2
Pseudostenophylax	4
Psychoglypha	4
Pycnopsyche	3
Molannidae:	
Molanna	2
Odontoceridae:	
Marilia	4
Psilotreta	4
Philopotamidae:	
Chimarra	3
Dolophilodes	4
Wormaldia	4
Phryganeidae:	
Agrypnia	1
Banksiola	0
Fabria	1
Oligostomis	3
Phryganea	1
Ptilostomis	1

Macroinvertebrate Taxa	Sensitivity Value
Polycentropodidae:	
Cyrnellus	1
Neureclipsis	2
Nyctiophylax	2
Polycentropus	---
Psychomyiidae:	
Lype	3
Psychomia	3
Rhyacophilidae:	
Rhyacophila	4
Sericostomatidae:	
Agarodes	3
Uenoidae:	
Neophylax	3
DAMSELFLIES:	
Calopterygidae:	
Calopteryx aequabilis	3
Calopteryx maculata	4
Hetaerina	2
Coenagrionidae:	
Amphiagrion	0
Argia	2
Chromagrion	2
Coenagrion	0
Enallagma antennatum	1
Enallagma aspersum	0
Enallagma basidens	0
Enallagma boreale	1
Enallagma carunculatum	1
Enallagma civile	0
Enallagma clausum	0
Enallagma cyanthigerum	0
Enallagma ebrium	0
Enallagma exsulans	2
Enallagma geminatum	1
Enallagma hageni	0
Enallagma signatum	1
Enallagma vesperum	1
Ischnura	0
Nehalennia	0
Lestidae:	
Lestes	0

Macroinvertebrate Taxa	Sensitivity Value
DRAGONFLIES:	
Aeshnidae:	
Aeshna	2
Anax	0
Basiaeschna	1
Boyeria	2
Nasiaeschna	1
Cordulegastridae:	
Cordulegaster	3
Corduliidae:	
Cordulia	1
Epitheca	1
Helocordulia	2
Neurocordulia	2
Somatochlora	3
Gomphidae:	
Agrigomphus	1
Dromogomphus	2
Gomphurus	2
Gomphus (=Hylogomphus)	3
Hagenius	2
Ophiogomphus	3
Phanogomphus (=Gomphus)	2
Stylogomphus	3
Stylurus	3
Libellulidae:	
Erythemis	1
Libellula	0
Ladona	0
Leucorrhinia	0
Libellula	0
Perithemis	0
Plathemis	0
Sympetrum	1
Tramea	0
Macromiidae:	
Didymops	2
Macromia	2
MAYFLIES:	
Ameletidae:	
Ameletus	4
Arthropleidae:	
Arthoplea	3

Macroinvertebrate Taxa	Sensitivity Value
Baetidae:	
Acentrella	3
Acerpenna macdunnoughi	3
Acerpenna pygmaeus	2
Apobaetis	?
Baetis armillatus	2
Baetis brunneicolor	3
Baetis cinctutus	2
Baetis dubium	1
Baetis flavistriga	1
Baetis intercalaris	2
Baetis pluto	2
Baetis punctiventris	3
Baetis tricaudatus	4
Baetis virile	1
Callibaetis	0
Centroptilum	3
Diphetor	3
Heterocloeon	2
Labiobaetis frondalis	2
Labiobaetis longipalpus	1
Labiobaetis propinquus	2
Paracloeodes	0
Procloeon	2
Pseudocentroptiloides	3
Baetiscidae:	
Baetisca	2
Caenidae:	
Brachycercus	2
Caenis	1
Cerobrachys	1
Ephemerellidae:	
Attenella	2
Drunella	4
Ephemerella aurivilli	4
Ephemerella (others)	3
Eurylophella aestiva	1
Eurylophella bicolor	3
Eurylophella colaxis	3
Eurylophella funeralis	4
Eurylophella lutulenta	1
Eurylophella temporalis	1
Serratella	3
Timpanoga (=Dannella)	3

Macroinvertebrate Taxa	Sensitivity Value
Ephemeridae:	
Ephemera guttulata	3
Ephemera simulans	2
Ephemera varia	3
Hexagenia atrocaudata	3
Hexagenia (others)	1
Litobrancha	3
Pentagenia	3
Heptageniidae:	
Anepeorus	1
Epeorus	4
Heptagenia	3
Leucrocuta	4
Nixe	3
Rhithrogenia	4
Stenacron	2
Stenonema exiguum	1
Stenonema femoratum	1
Stenonema integrum	2
Stenonema ithaca	2
Stenonema luteum	4
Stenonema mediopunctatum	3
Stenonema modestum	2
Stenonema pulchellum	1
Stenonema rubrum	2
Stenonema terminatum	2
Stenonema vicarium	3
Isonychiidae:	
Isonychia	2
Leptohyphidae:	
Tricorythodes	2
Leptophlebiidae:	
Choroterpes	3
Habrophlebiodes	2
Leptophlebia	1
Paraleptophlebia	3
Metretopodidae:	
Siphloplecton	2
Oligoneuriidae:	
Homoeoneuria	2
Polymitarcyidae:	
Ephoron	3
Tortopus	1
Potamanthidae:	
Anthropotamus	2

Macroinvertebrate Taxa	Sensitivity Value
Pseudironidae:	
Pseudiron	2
Siphlonuridae:	
Parameletus	3
Siphlonurus	2
STONEFLIES:	
Capniidae :	
Allocapnia	4
Capnia	4
Paracapnia	3
Chloroperlidae:	
Alloperla	4
Haploperla	3
Suwallia	4
Sweltsa	4
Leuctridae:	
Leuctra	4
Paraleuctra	4
Nemouridae:	
Amphinemura	4
Nemoura	3
Ostrocerca	4
Pananemoura	4
Podmosta	4
Prostoia	3
Shipsa	3
Soyedina	4
Peltoperlidae:	
Peltoperla	3
Tallaperla	3
Perlidae:	
Acroneuria	2
Agnetina	3
Attaneuria	2
Neoperla	3
Paragnetina	3
Perlesta	2
Perlinella	3

Macroinvertebrate Taxa	Sensitivity Value	Macroinvertebrate Taxa	Sensitivity Value
Perlodidae:		Diamesa	3
Clioperla	3	Dicrotendipes	0
Cultus	4	Diplocladius	2
Helopicus	?	Doncricotopus	3
Isogenoides	4	Einfeldia	0
Isoperla bilineata	2	Endochironomus	0
Isoperla nana	2	Epoicocladius	2
Isoperla (others)	4	Eukiefferiella	3
Malirekus	4	Glyptotendipes	0
Pteronarcyidae:		Harnischia	1
Pteronarcys	3	Heleniella	3
Taeniopterygidae:		Helopelopia	3
Arcynopteryx	4	Heterotanytarsus	0
Oemopteryx	4	Heterotrissocladius	1
Strophopteryx	4	Hydrobaenus	1
Taeniopteryx burksi	2	Labrundinia	1
Taeniopteryx (others)	3	Larsia	1
		Lauterbourniella	0
TRUE FLIES:		Limnophyes	1
Athericidae:		Macropelopia	3
Atherix	3	Meropelopia	3
Blephariceridae:		Microchironomus	1
Blepharicera	4	Microcricotopus	1
Ceratopogonidae	0	Micropsectra	3
Chironomidae:		Microtendipes	2
Ablabesmyia	2	Monodiamesa	1
Apsectrotanypus	4	Nanocladius	3
Brilliaparva	4	Natarsia	3
Brillia (others)	2	Nilotanypus	2
Brundiniella	4	Nilothauma	1
Cardiocladius	2	Odontomesa	1
Chaetocladius	1	Orthocladius	---
Chernovskiia	1	Pagastia	3
Chironomus	0	Pagastiella	0
Cladopelma	1	Parachaetocladius	3
Cladotanytarsus	2	Parachironomus	1
Clinotanypus	1	Paracladopelma	2
Coelotanypus	1	Parakiefferiella	1
Conchapelopia	2	Paralauterborniella	0
Corynoneura	2	Parametriocnemus	3
Cricotopus	---	Paratanytarsus	1
Cryptochironomus	1	Paratendipes	2
Cryptotendipes	2	Pentaneura	2
Demicryptochironomus	1	Phaenopsectra	1

Macroinvertebrate Taxa	Sensitivity Value
Polypedilum	1
Potthastia	1
Procladius	0
Prodiamesa	3
Protanypus	0
Psectrocladius	1
Psectrotanypus	0
Pseudochironomus	1
Rheocricotopus	2
Rheopelopia	3
Rheotanytarsus	2
Robackia	2
Saetheria	2
Stempellina	2
Stempellinella	3
Stenochironomus	2
Stictochironomus	2
Sympotthastia	3
Syndiamesa	3
Synorthocladius	2
Tanypus	1
Tanytarsus	2
Thienemanniella	2
Thienemannimyia	2
Tribelos	1
Trissopelopia	2
Tvetenia	2
Xenochironomus	2
Xylotopus	2
Zalutschia	0
Zavrelimyia	2
Culicidae	0
Dixidae	0
Dolichopodidae	2
Empididae	2
Ephydridae	1
Muscidae	1
Psychodidae	0
Ptychopteridae	1
Simuliidae	2
Stratiomyidae	0
Syrphidae	0
Tabanidae:	
Chrysops	2
Tabanus	0

Macroinvertebrate Taxa	Sensitivity Value
Tipulidae:	
Antocha	3
Dicranota	3
Erioptera	1
Helius	1
Hexatoma	2
Limnophila	2
Limonia	2
Pedicia	2
Pilaria	1
Pseudolimnophila	3
Tipula	---
Crustaceans:	
AMPHIPODS:	
Crangonyctidae:	
Crangonyx pseudogracilis	3
Crangonyx rivularis	3
Crangonyx (others)	2
Gammaridae:	
Gammarus fasciatus	2
Gammarus lacustris	3
Gammarus pseudolimneus	3
Talitridae:	
Hyallela	2
CRAYFISH:	
Cambaridae:	
Cambarus	1
Orconectes	2
Palaemonetidae:	
Palaemonetes	3
ISOPODS:	
Asellidae:	
Caecidotea	1
Lirceus	2
Molluscs:	
CLAMS:	
Sphaeriidae:	
Musculium lacustre	1
Musculium partumeium	1
Musculium securis	1
Musculium transversum	2
Pisidium	---

Macroinvertebrate Taxa	Sensitivity Value
Sphaerium fabale	3
Sphaerium occidentale	0
Sphaerium rhomboideum	1
Sphaerium simile	1
Sphaerium striatinum	2
MUSSELS:	
Dreissenidae:	
Dreissena	0
Unionidae:	
Actinonaias carinata	2
Alasmidonta marginata	3
Alasmidonta viridis	3
Amblema plicata	2
Anodontoides ferussacianus	3
Atinonaias carinata	2
Carunculina parva	1
Cyclonaias tuberculata	2
Elliptio dilatata	1
Epioblasma (=Dysnomia)	2
Fusconaia flava	1
Lampsilis fasciola	3
Lampsilis radiata	1
Lampsilis ventricosa	1
Lasmigona complanata	1
Lasmigona compressa	4
Lasmigona costata	2
Leptodea fragilis	1
Ligumia nasuta	0
Ligumia recta	1
Obliquaria reflexa	1
Obovaria subrotunda	2
Pleurobema coccineum	1
Proptera alata	0
Ptychobranchus fasciolaris	3
Pyganodon (=Anodonta)	1
Quadrula quadrula	2
Quadrula pustulosa	1
Simpsoniconcha ambigua	2
Strophitus undulatus	3
Truncilla	2
Villosa fabalis	2
Villosa iris	2

Macroinvertebrate Taxa	Sensitivity Value
SNAILS:	
Ancylidae:	
Ferrissia	2
Bithyniidae:	
Bithynia	1
Hydrobiidae:	
Amnicola	2
Birgella (=Somatogyrus)	2
Cincinnatia	1
Fontigens	3
Probythinella	2
Lymnaeidae:	
Bulimnea	1
Fossaria	1
Lymnaea	1
Pseudosuccinea	0
Stagnicola	0
Physidae:	
Physella	0
Planorbidae:	
Gyraulus	1
Heliosoma	1
Planorbella	0
Planorbula	1
Promenetus	2
Pleuroceridae:	
Elimia (=Goniobasis)	2
Pleurocera	1
Valvatidae:	
Valvata	2
Viviparidae:	
Campeloma	1
Cipangopaludina	1
Viviparus	1
Annelids:	
LEECHES:	
Erpobdellidae:	
Dina dubia	1
Dina parva	0
Erpobdella	1
Mooreobdella	2
Nephelopsis	2

Macroinvertebrate Taxa	Sensitivity Value	Macroinvertebrate Taxa	Sensitivity Value
Hirudinidae:		Ilyodrilus	0
Haemopsis	1	Isochaetides curvisetosus	3
Macrobdella	0	Isochaetides freyi	1
Glossiphoniidae:		Limnodrilus	0
Alboglossiphonia	?	Potamothrix bavaricus	1
Glossiphonia	2	Potamothrix moldaviensis	2
Helobdella elongata	1	Potamothrix vejdovskyi	2
Helobdella fusca	2	Quistadrilus	0
Helobdella papillata	1	Rhyacodrilus	2
Helobdella stagnalis	2	Spirosperma	1
Helobdella triserialis	2	Tasserkidrilus	2
Placobdella	1	Tubifex	0
WORMS:			
Lumbriculidae	4	Platyhelminthes:	
Tubificidae:		FLATWORMS:	
Aulodrilus	1	Neorhadocoela	1
Bothrioneurum	2	Tricladida	3
Branchiura	0		

If the density of organisms is < 25 per 0.05 sq. m. then:

Cheumatopsyche	1
Cricotopus	1
Orthocladius	1
Pisidium	1

Appendix B: Key to the taxonomic resolution and main taxonomic references for the identification of macroinvertebrates used in the BioMAP water quality index. Note: only late instars (nymphs) or adults can be identified to species; younger individuals typically can only be identified to genus. Headings A through E list the taxonomic resolution and reference for the main groups of benthic macroinvertebrates. Sub-headings denote changes to the taxonomic resolution or reference for the identified sub-group (order, family, genus).

Taxon	Taxonomic Resolution	Taxonomic Reference *
A. **INSECTS**	Genus	Merritt & Cummins 1996
1. Beetles		
a. Elmidae	Species (adults)	Hilsenhoff & Schmude 1992
		Brown 1972
2. Bugs		
a. Sigara	Species (adults)	Hilsenhoff 1984
3. Caddisflies	Genus	Wiggins 1996
a. Hydropsyche	Species	Schefter and Wiggins 1986
		Schuster and Etnier 1978
4. Damselflies	Genus	Westfall and May 1996
a. Calopteryx	Species	Westfall and May 1996
b. Enallagma	Species	Westfall and May 1996
5. Mayflies		
a. Acerpenna	Species	Morihara & McCafferty 1979
b. Baetis	Species	McCafferty & Walz 1990
		Morihara & McCafferty 1979
c. Ephemerella	Species	Allan and Edmunds 1965
d. Ephemeridae	Species	McCafferty 1975
e. Eurylophella	Species	Allen & Edmunds 1963
f. Labiobaetis	Species	McCafferty and Waltz 1995
g. Stenonema	Species	Bednarik & McCafferty 1979
6. Stoneflies	Genus	Stewart & Stark 1988
a. Isoperla	Species	Hitchcock 1974
b. Taeniopteryx	Species	Hitchcock 1974

Appendix B: continued.

Taxon	Taxonomic Resolution	Taxonomic Reference *
B. CRUSTACEANS	Genus	Pennak 1989
1. Amphipods	Genus	Bousfield 1967
a. Gammarus	Species	Holsinger 1976; Bousfield 1967
2. Crayfishes	Genus	Crocker & Barr 1968
C. MOLLUSCS	Genus	Burch 1989; Clarke 1981
1. Clams		
a. Musculium	Species	Clarke 1981
b. Sphaerium	Species	Clarke 1981
2. Mussels	Species	Clarke 1981
D. ANNELIDS	Genus	Brinkhurst 1986; Klemm 1985
1. Leeches		
a. Dina	Species	Klemm 1985
b. Helobdella	Species	Klemm 1985
2. Worms		
a. Lumbriculidae	Family	Brinkhurst 1986
b. Isochaetides	Species	Brinkhurst 1986
c. Potamothrix	Species	Brinkhurst 1986
E. FLATWORMS	Order	Pennak 1989

* Taxonomic References:

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Appendix C: Example Excel spreadsheet showing calculations of the BioMAP water quality index from benthic data. Formulas in cells noted below spreadsheet.

BioMAP example

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2	Example spreadsheet to calculate the BioMAP water quality index from benthic data.											
3												
4	Taxa	Density				Ln(density+1)				exp(SV)*Ln(density+1)		
5		Site 1		Site 2	SV	Site 1		Site 2	exp(SV)	Site 1		Site 2
6												
7	Nigronia	5		6	3	1.79		1.95	20.09	35.9885		39.0847
8	Lutrochus	10		19	3	2.40		3.00	20.09	48.163		60.1709
9	Glossosoma	8			4	2.20		0.00	54.60	119.964		0
10	Lepidostoma	21		4	4	3.09		1.61	54.60	168.765		87.8723
11	Diphetor	35		24	3	3.58		3.22	20.09	71.9769		64.6528
12	Amphinemura	16		18	4	2.83		2.94	54.60	154.688		160.761
13	Diamesa	19		6	3	3.00		1.95	20.09	60.1709		39.0847
14												
15	Total Sum	114		77		18.89		14.66		659.72		451.63
16												
17	BioMAP WQI	34.9		30.8								
18												
19												
20												
21												
22												

Number of individuals from benthic sample

Sensitivity Value of taxon from Appendix A

=ln(B13+1)

=exp(E12)

=I13*H13

=sum(H7:H13)

=sum(J7:J13)

=L15/H15

List of BioMAP Reports *

1. **Program Reports**:

Griffiths, R.W. 1993. BioMAP: Concepts, Protocols and Sampling Procedures for the Southwestern Region of Ontario. BioMAP Report SWR-1. 30 pp.

Griffiths, R.W. 1996. A Biological Measure of Water Quality for Creeks, Streams and Rivers. BioMAP Report SWR-4. 40 pp.

2. **Water Quality Assessment Reports**:

Westwood, J.D. and M. Johns. 1993. Environmental Assessment of the Teeswater River at the Village of Teeswater, Bruce County. BioMAP Report SWR-2. 22 pp.

Westwood, J.D. and R.W. Griffiths. 1994. Environmental Assessment of Mill Creek in the vicinity of the Port Elgin Landfill Site, Bruce County. BioMAP Report SWR-3. 15 pp.

* available from the Ministry of the Environment and Energy, Southwestern Region, London, Ontario.

Date Due
